Simulations of Ion-Hose Instability with Pressure Profiles For DARHT-II Long-Pulse Experiments

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Abstract

Ion-hose instability growth of the 2-μs electron beam pulses will be studied during the Phase-II commissioning of the DARHT-II Facility. We have done simulations in support of the experiment using pressure profiles estimated for different pumping arrangements along the accelerator. Results of these simulations are reported in this paper and compared to simulation results reported previously using constant pressure profile along the accelerator. Good agreement is found.

I. INTRODUCTION

During the Phase-II Commissioning of the DARHT-II (second axis of the Dual-Axis Radiographic Hydrodynamics Test) Facility, Long-Pulse Experiments [1] (LPE) will focus on the stability of the 2-μs beam pulse against beam-breakup and ion-hose effects. The goal is to demonstrate that beam-breakup and ion-hose instabilities will not cause the DARHT-II beam to become unacceptable for radiographic applications.

In this paper, we will report simulation results of ion-hose instability for the LPE with different pressure profile along the accelerator. Ion-hose instability of DARHT-II have been studied previously and reported in Ref. 2-6. Simulation results for LPE with constant pressure profiles along the accelerator have been reported in Ref. [7].

II. SIMULATIONS CODES

We studied ion-hose instability with two computer codes, a spread-mass (SM) code [8] and a particle-in-cell code, LSP [9].

The SM code was initially developed at ATK-MR. Its formulation using the spread-mass method is a simplified treatment of beam dynamics and has been documented in Ref. [2]. The original version of the code assumed beam and accelerator parameters that were uniform along the length of the accelerator. These parameters include the solenoidal magnetic field, beam energy, and beam radius. The code was later improved, as documented in Ref. [7], by including these parameters as functions of longitudinal distance along the accelerator. The effect of the radial magnetic field introduced by the varying longitudinal magnetic field was also included. Such a radial field will cause a rotation of the beam centroid around the accelerator axis. For the work reported here, we have extended the code so that residual gas pressure profiles can be input to represent more truthfully the estimated pressure profile in the accelerator due to different pumping arrangements.

LSP is a particle-in-cell code developed in ATK-MR. It continuously generates ions by the beam through impact ionizations. The positions of the beam electrons and ions are tracked and propagated using electromagnetic forces self-consistently calculated according to the distributions of the electrons and ions. Besides calculating the centroids of the beam and ion-channel, it also calculates the beam envelope and emittance.

LSP simulations, though represent fully the physics of the simulated system, require long running time in large computers. Our SM code, carefully benchmarked against the particle-in-cell code LSP, offers fast results with typical running time of a few minutes in a PC and is a reasonably reliable tool for surveying the parameter space.

We will show here typical results of the benchmarking of our SM code against LSP. Two cases were compared: a) H_2O gas excited with an input beam displacement oscillation at 12-MHz; b) Ar gas excited with an input beam displacement oscillation at 8.4-MHz. The frequencies of 12 and 8.4 MHz were chosen because they were the estimated ion-hose resonance frequencies. Both SM and LSP simulations used same initial displacements and accelerator parameters for Phase I Commissioning as listed in the "Benchmark" column in Table 1.

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14. ABSTRACT
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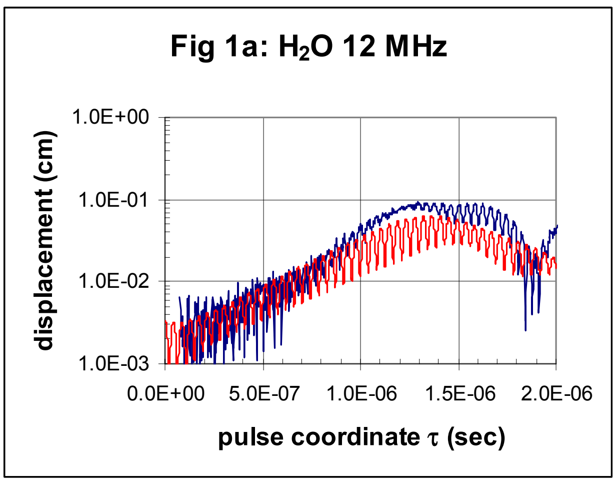
Table 1. Accelerator parameters used for the benchmarking and LPE simulations

Parameters	Benchmark	LPE
Accelerator length (cm)	2250	2750
Initial Beam Energy (MeV)	4.2	3.1
Final beam Energy (MeV)	11.34	8.1
Accelerator current (kA)	1.4	1.4
Average rms beam radius (mm)	7.2	5.5
Average B_z (Gauss)	700	625
Gas pressure (torr)	$1x10^{-6}$	$0.1\text{-}1x10^{-6}$
Beam pulse length (μs)	2	2

LSP and SM results are shown for these benchmarking cases for H_2O and Ar gases, respectively, in Figs 1a and 1b. In these figures, beam displacements calculated at the end of the accelerator are plotted as a function of position along the pulse, denoted by τ as pulse coordinate measured from the head of the pulse. SM results show good qualitative agreement with LSP results and predict growth approximately a factor of two lower than LSP.



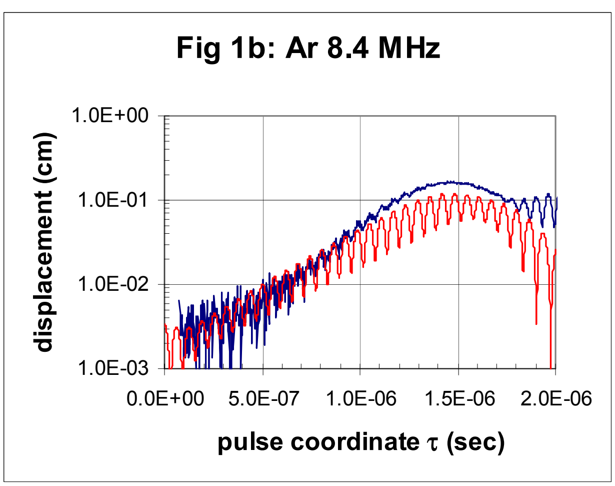


Figure 1. Comparison of LSP (blue) and SM (red) results for benchmark cases (a) H_2O and (b) Ar.

III. LPE ION-HOSE SIMULATIONS

Ion-hose simulations have been reported in Ref. [7] for the Long-Pulse Experiments. In that report, we showed results of ion-hose calculations for LPE for gases including H_2O, Ar, Kr, Xe, and N_2. Those calculations were done assuming a constant pressure along the accelerator. Their results show no ion-hose instability growth until the pressure level reaches a few times 10^{-7} torr.

We have now extended those simulations to include pressure profiles estimated along the accelerator according to different pumping arrangements. The SM code with recent modifications to take into account of varying pressure levels along the accelerator direction (z) was used for the simulation. We have done calculations for Xe and N_2. The results are summarized here and compared to results in Ref. [7].

The pressure profile in the accelerator was calculated using the finite-difference code VACCALC [10] developed at SLAC. Input to the code included established out-gassing rates and pumping speeds. Calculated results have been compared to measured data showing good agreement.

The accelerator modeled consists of eight cellblocks. There is one vacuum pump between each cell block and a pump at both ends of the accelerator. The pressure profiles were calculated for different pumping arrangements with different number of vacuum pumps turned off. These pumping arrangements are summarized in Table 2 with associated pressure profiles shown in Fig. 2. Accelerator parameters are summarized in Table 1.

Table 2. List of vacuum pressure profiles

Name	Description	Average pressure
base	all pumps running	$5.0x10^{-8}$ torr
4	four pumps off	$1.2x10^{-7}$ torr
6	six pumps off	$2.9x10^{-7}$ torr
all	all pumps off	$3.6x10^{-7}$ torr

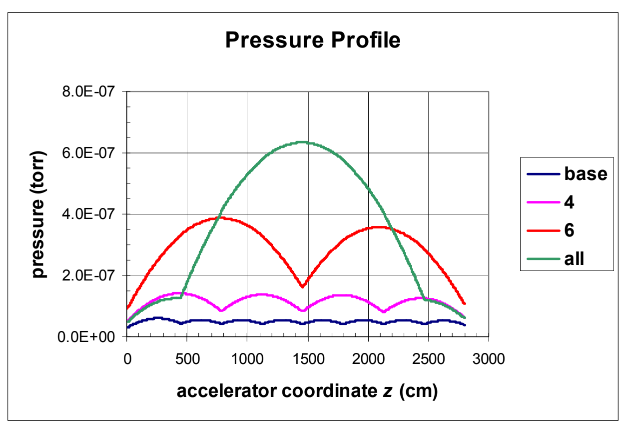
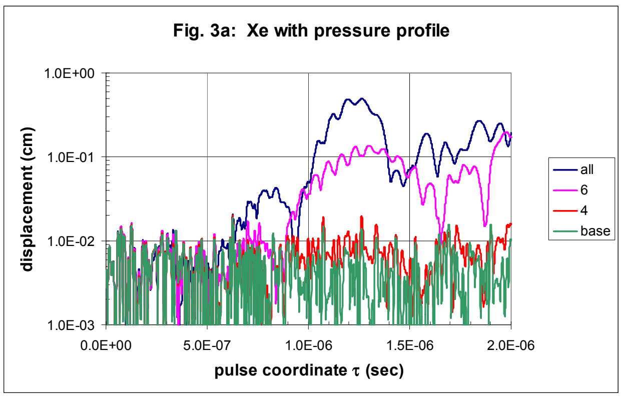


Figure 2. Pressure profiles along the accelerator with different pumping arrangements. Description of the pumping arrangements is summarized in Table 2.

The beam excitation for the calculations was a sum of sinusoidal beam oscillations at 100 discrete frequencies equally spaced between 0 and 50 MHz. The initial amplitude of these oscillations is 0.001 cm. Calculations were done for gases Xe and N_2. Xe was used because it gives the largest ion-hose instability growth. N_2 is used to simulate air.

Results of the ion-hose calculations are shown in Figure 3. The beam displacement along the pulse calculated at the end of the accelerator is plotted for different pressure profiles. We do not see any instability growth until six or more pumps were turned off corresponding to an average pressure reaching above 3×10^{-7} torr. This is in agreement with the results for constant pressures [7]. For comparison, results for constant pressure are shown in Fig. 4.



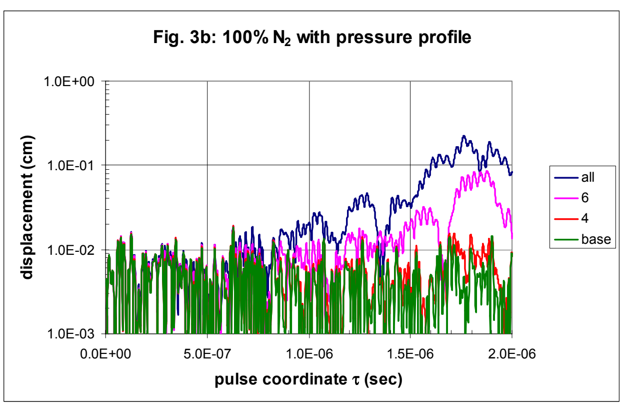
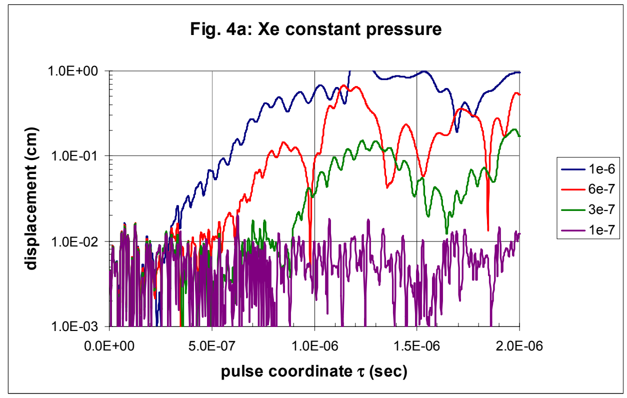


Figure 3. Ion-hose calculation results for (a) Xe and (b) N_2 showing the beam displacement along the beam pulse for different pressure profiles



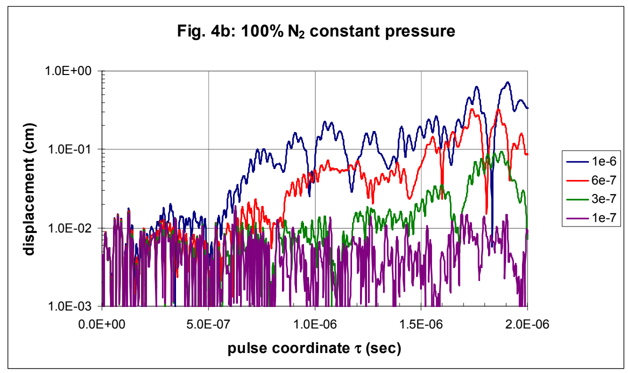


Figure 4. Ion-hose calculation results for (a) Xe and (b) N_2 showing the beam displacement along the beam pulse assuming constant pressure along the accelerator

Results in Figs 3 and 4 can be summarized by calculating the average beam displacement for the last quarter (1.5 to 2.0 μs) of the pulse and plotting them against average pressures (Fig. 5). They show the qualitative agreement between calculations between constant pressure and pressure profile and growths is faster for calculations with pressure profiles after 3×10^{-7} torr.

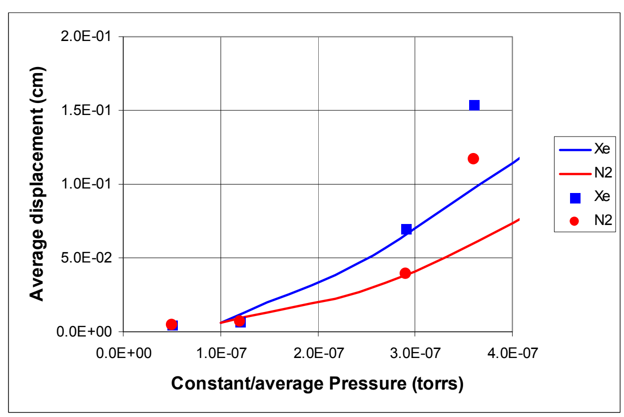


Figure 5. Average beam displacement of the last quarter of the beam pulse. Blue=Xe, Red=N_2. Curve=constant pressure, Symbol=pressure profile.

IV. CONCLUSION

Ion-hose calculations for DARHT-II Long-Pulse Experiments with pressure profiles along the accelerator corresponding to different pumping arrangements were performed. We do not see ion-hose instability growth until the pressure is close to or above $3x10^{-7}$ torr. Results of these calculations using pressure profiles are in general agreement with our previous calculations with constant pressure levels assumed along the accelerator.

V. ACKNOWLEDGEMENT

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